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Identifying and Tracking Gas Suicides in the U.S. Using the National Violent Death Reporting System, 2005–2012



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Introduction: Identifying the source and specific type of gas used in suicides is difficult using most data systems owing to limitations in ICD-10 coding. The National Violent Death Reporting System (NVDRS), with its rich collection of both coded and free-text variables, has the potential to overcome these limitations. This study used a multipronged approach to identify gas-specific suicides in NVDRS and to track the incidence of these suicides over time.

Methods: Using suicide cases from the 16 NVDRS states that participated throughout 2005–2012, free-text and code searches were conducted for four types of variables—incident narratives, coroner/medical examiner cause-of-death statements, cause-of-death codes, and substance names—to identify suicides by carbon monoxide, helium, hydrogen sulfide, and four other gases. All analyses were conducted in 2015.

Results: Approximately 4% (3,242 of 80,715) of suicides recorded in NVDRS over the study period were the result of gas inhalation. Of these, the majority (73%) were carbon monoxide suicides (almost exclusively from motor vehicle exhaust and charcoal burning). Other types of gas (most notably helium), once rare, are now more common: At the start of the study period non-carbon monoxide gas suicides represented 15% of all gas suicides; at the end of the study period, they represented 40%.

Conclusions: Public health policies to reduce a suicidal person's access to more lethal suicide methods require a reliable source of surveillance data on specific methods used in suicide. Small changes to NVDRS could make it an efficient and nimble surveillance system for tracking these deaths.

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Introduction

Suicide by inhalation of gases accounts for roughly 5%–15% of all suicides worldwide.^{1–7} Although carbon monoxide (CO) remains the gas most commonly used in these deaths, patterns of gas inhalation suicide, as well as patterns in the sources of gases,

have changed substantially over the past 40 years. In particular, rates of suicide by inhalation of motor vehicle exhaust gas have fallen steadily since the widespread inclusion of catalytic converters in new cars.^{8–16} More recently, the incidence of suicide by inhalation of CO from charcoal burning, which represented no more than 1% of all suicides throughout Asia/Southeast Asia in the mid-1990s, increased dramatically, accounting for as many as 25% of all suicides in Hong Kong and 30% of suicides in Taiwan in the mid-2000s.^{4,17,18} Although suicide involving inhalation of other types of gas has been less well characterized, a number of descriptive studies have noted recent increases in suicide by helium in the U.S.^{19–21} and elsewhere,^{1,22,23} and by hydrogen sulfide in Japan.²⁴

A major challenge to tracking gas suicides by gas type and source (e.g., CO from motor vehicle exhaust) is that available mortality data are not, in general, designed to

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provide this information. One reason for this is that data sources such as the U.S. National Center for Health Statistics mortality data rely on ICD coding to describe causes of death. However, the ICD is not, for the most part, designed to capture this information. For example, using ICD codes it is not possible to distinguish deaths caused by motor vehicle exhaust from deaths caused by CO from other sources, such as charcoal burning,²⁵ because the ICD-10 for CO poisoning (T58) does not allow for specification of the source of CO. More importantly, specific ICD-10 codes are available for only a limited number of specific gases (e.g., CO and hydrogen sulfide, but not helium, nitrogen, or propane).

The National Violent Death Reporting System (NVDRS) captures information in addition to ICD-coded underlying cause of death codes and, as such, has the potential to capture gas-specific suicides. As currently designed, however, it does not do so efficiently. For example, specific gases and their sources may be mentioned in the free text narrative summarizing the medical examiner report, but this information is neither easily nor routinely coded in structured NVDRS variables. The current study uses comprehensive data from 16 states in NVDRS to explore the potential of the rich data collected by the system to:

1. identify and characterize gas suicides by type and source; and
2. contingent on establishing that NVDRS can indeed be used to identify gas-specific suicides, for those gases for which there are a sufficient number of cases, present trends over the study period.

Methods

Study Sample

Data for the study come from the NVDRS Restricted Access Data Set. NVDRS provides a census of all deaths classified on the death certificate as suicide, homicide, legal intervention, unintentional firearm injury, or injury of unknown intent in 32 U.S. states; data for the study are from the 16 states that had complete data for the years 2005–2012 (Alaska, Colorado, Georgia, Kentucky, Maryland, Massachusetts, New Jersey, New Mexico, North Carolina, Oklahoma, Oregon, Rhode Island, South Carolina, Utah, Virginia, and Wisconsin). An NVDRS abstractor at the state level collects data from death certificates, police reports, crime lab reports, and coroner/medical examiner records for each death. NVDRS has been described in further detail elsewhere.²⁶ The Harvard T.H. Chan School of Public Health's IRB approved use of the data.

Statistical Analysis

The data set used for this study comprised 80,715 deaths recorded by the NVDRS abstractor as suicides over the study period.²⁷ Within this subset, gas suicides were identified via a search of two sets of text variables and two sets of coded variables included in the

NVDRS Restricted Access Data Set. Potential cases were any suicide that met the search criteria.

Searched text variables were:

1. death cause (three text fields from the death certificate that capture the coroner/medical examiner's brief verbatim statements describing causes of death, e.g., "asphyxiation," "helium inhalation"); and
2. incident narratives (two text fields written by the abstractor that summarize the coroner/medical examiner and law enforcement reports).

Potential cases were those in which these text fields included any mention of specific gases (e.g., helium, hydrogen sulfide, nitrogen). Specific gases searched for were drawn from the gas suicide literature as well as from other compilations of gases (e.g., anesthetic gases; [Table 1](#) lists complete search terms).

Routinely collected, structured variables searched were:

1. multiple cause of death (ten fields, ICD-10 codes):
 - X64 (intentional self-poisoning by and exposure to other and unspecified drugs, medicaments, and biological substances);
 - X67 (intentional self-poisoning by and exposure to other gases and vapors);
 - T41 (toxic effect of anesthetics and therapeutic gases);
 - T48 (poisoning by, adverse effect of, and underdosing of agents primarily acting on smooth and skeletal muscles and the respiratory system);
 - T53 (toxic effect of halogen derivatives of aliphatic and aromatic hydrocarbons);
 - T58 (toxic effect of CO);
 - T59 (toxic effect of other gases, fumes, and vapors, which includes T59.6, hydrogen sulfide); and
2. substances contributing to death: ten fields that capture NVDRS codes for substances that tested positive on postmortem toxicologic testing and contributed to death.

Deaths identified through any of the four sources were considered possible gas-specific suicides. Once the universe of all potential gas suicides was identified, at least one of the authors (AM, all; DA, CB, subsets) assessed each case individually to confirm that the suicide was the result of gas inhalation by the specified gas. These assessments, by virtue of the search strategy, could only identify false positives, that is, cases in which the gas in question was not causally related to the suicide, such as when the narrative mentioned that a gas had been used in an earlier suicide attempt or when the gas in question was not the cause of death.

Following convention,²⁵ cases in which CO inhalation contributed to the suicide but was secondary to a fire (e.g., the decedent lit himself on fire or set his home or car on fire while inside) were excluded. Cases of probable fire-related CO deaths were defined as cases in which any multiple cause of death field included the ICD-10 code X76 (intentional self-harm by smoke, fire, or flames), or any of the NVDRS weapons variables (three fields) were coded as "fire or burns."

The CO suicides in which charcoal burning was the likely source were identified using text field searches (e.g., for "charcoal" or "briquette"). The source of CO for the remaining CO deaths was not identified. However, a review by two of the authors (AM, DA) found that the source of CO in 99% of a random sample of 225 CO

Table 1. Gas Suicides by Case Identification Source: Sensitivity and Positive Predictive Value (16 NVDRS States, 2005–2012)

Gas (1)	Number of true cases (% of total gas suicides)	Case identification source: Sensitivity (PPV)			
		Coroner medical examiner cause of death	Abstractor's incident narratives	Evidence of specific gas—toxicology testing	Cause of death codes (ICD codes)
CO	2,367 (73%)	0.88 (0.99)	0.79 (0.80)	0.89 (0.94)	0.28 (0.98)
Helium	665 (21%)	0.64 (1.00)	0.95 (0.98)	0.10 (1.00)	na
Hydrogen sulfide	44 (1%)	0.45 (0.87)	0.93 (0.73)	0.52 (0.96)	0.48 (1.00)
Nitrogen	36 (1%)	0.61 (0.96)	0.90 (1.00)	0.03 (1.00)	na
Nitrous oxide	26 (1%)	0.50 (1.00)	0.88 (0.72)	0.27 (0.88)	na
Propane	26 (1%)	0.62 (0.80)	0.96 (0.40)	0.42 (1.00)	na
Natural gas	16 (<1%)	0.63 (1.00)	0.94 (0.54)	0.19 (1.00)	na
Other gas	62 (2%)				
Total	3,242				

Note: Search terms for gases included: carbon monoxide (CO, carbox*, coal, grill, hibachi, brique*, brike*); helium; hydrogen sulfide (hydrogen sulphide, H₂S, toilet bowl cleaner, detergent, muriatic acid; hydrochloric acid); nitrogen; nitrous oxide (laughing gas), propane; natural gas. Other gases searched include: anesthetic gases, refrigerant gases, heating gases, specifically: neon, argon, krypton, xenon, radon, unctonium, carbon dioxide, ozone, chlorine, desflurane, isoflurane, sevoflurane, methyl chloride, hydrogen chloride, phosphine, dichloropropene, chloropicrin, methyl isocyanide, hydrogen cyanide, anhydrous ammonia, arsenic, arsine, bis peroxide, boron, bromine, bromomethane, chlorofluoro*, cyanogen, diazomethane, diborane, dichlorosilane, fluorine, fluoride, formaldehyde, germane, hexaethyl tetraphosphate, nickel tetracarbonyl, osmium, perfluoroisobutylene, phosgene, selenium, phosphate, acetylene, butane.

na, not applicable; NVDRS, National Violent Death Reporting System; PPV, positive predictive value.

deaths for which narrative information was available and charcoal was not explicitly mentioned was probable or confirmed motor vehicle or other engine exhaust (e.g., lawn mower, generator).

Despite the richness of NVDRS data, NVDRS has not yet been used to identify these suicides, or to assess changes in their incidence (overall or by specific gas) over time. The authors took advantage of the presence of both open text and coded variables in NVDRS to identify the universe of gas suicides. The sensitivity of each component of the strategy was calculated (e.g., the proportion of all true gas-specific cases identified from the narrative text search only) as was the positive predictive value (the proportion of cases identified by each specific search component that were true cases). Trends in gas-specific suicide over the study period were assessed for overall gas suicide; CO (by source) suicide; and helium suicide using negative binomial regression techniques, with annual gas-specific suicide counts as the dependent variable and total population (across NVDRS states) for each year as the exposure. Incidence rate ratios (IRRs) and 95% CIs were estimated, with IRRs that did not include 1.00 considered statistically significant.

All analyses for this study were conducted in 2015 using JMP, version 12, and Stata, version 14.

Results

Of the 80,715 suicides in the data set, 3,242 (4%) were suicides due to gas. These 3,242 cases represented 86% of the 3,776 possible gas suicides identified through the search strategy. The 14% of potential cases excluded were

primarily those in which a gas was mentioned in a text field but was not, on review, the cause of death.

Approximately three quarters (2,367, 73%) of the confirmed gas suicides were the result of CO poisoning (Table 1). In 310 (13%) of these 2,367 CO deaths, the source was charcoal burning (Table 2). For the large majority of the remaining CO cases, the source of CO was motor vehicle exhaust gas (although some cases were CO exhaust from other types of engines, including generators, lawn mowers, and others; not shown). Of the remaining 875 non-CO gas specific suicides identified in the search (27% of total gas suicides), by far the largest number (665, 77% of non-CO gas suicides) were the result of asphyxiation by helium, followed by hydrogen sulfide (44, 5%), nitrogen (36, 4%), nitrous oxide (26, 3%), propane (26, 3%), and natural gas (16, 2%). Suicide by other or unspecified gases (including anesthetic gases, refrigerant gases, and others) made up the remaining 62 (2%) gas suicide cases (Table 2).

Although gas-related suicides overall were stable over the study period (IRR=1.00, 95% CI=0.98, 1.01), non-CO suicides increased (from 15% in 2005 to 42% in 2012, IRR=1.21, 95% CI=1.14, 1.28) and total CO suicides declined (IRR=0.93, 95% CI=0.91, 0.95), owing to a decline in non-charcoal burning suicides (IRR=0.92, 95% CI=0.90, 0.94; Figure 1). The decline in non-charcoal burning CO suicides appears, for those gases for which

Table 2. Trends in Gas-Specific Suicides (16 NVDRS States, 2005–2012)

Type of gas	2005	2006	2007	2008	2009	2010	2011	2012	Total
Carbon monoxide (CO)	336	334	370	278	307	261	247	234	2,367
CO, non-charcoal	311 (93%)	304 (91%)	320 (86%)	236 (85%)	264 (86%)	213 (82%)	213 (86%)	196 (84%)	2,057 (87%)
CO, charcoal burning	25 (7%)	30 (9%)	50 (14%)	42 (15%)	43 (14%)	48 (18%)	34 (14%)	38 (16%)	310 (13%)
Non-CO gases	61	54	60	67	118	170	178	167	875
Helium	45 (73%)	45 (83%)	45 (75%)	53 (79%)	94 (80%)	128 (75%)	133 (75%)	122 (73%)	665 (76%)
Hydrogen sulfide	0	0	0	2 (3%)	4 (3%)	11 (6%)	17 (10%)	10 (6%)	44 (5%)
Nitrogen	1 (2%)	0	1 (2%)	0	3 (3%)	10 (6%)	7 (4%)	14 (8%)	36 (4%)
Nitrous oxide	4 (7%)	1 (2%)	0	2 (3%)	4 (3%)	3 (2%)	4 (2%)	8 (5%)	26 (3%)
Propane	3 (5%)	1 (2%)	7 (12%)	2 (3%)	2 (2%)	4 (2%)	4 (2%)	3 (2%)	26 (3%)
Natural gas	3 (5%)	1 (2%)	3 (5%)	3 (4%)	2 (2%)	1 (1%)	2 (1%)	1 (1%)	16 (2%)
Other gas	5 (8%)	6 (11%)	4 (7%)	5 (7%)	9 (8%)	13 (8%)	11 (6%)	9 (6%)	62 (7%)
Total gas suicides (CO + non-CO)	397	388	430	345	425	431	425	401	3,242
Population	77,773,677	78,812,117	79,779,499	80,716,283	81,587,293	82,186,435	83,019,177	83,708,039	

NVDRS, National Violent Death Reporting System.

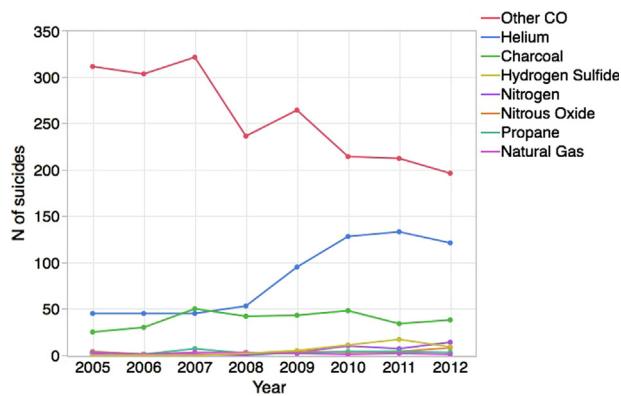


Figure 1. Time trends in suicides by gas 2005–2012.

Note: Data are from NVDRS 2005–2012 for Alaska, Colorado, Georgia, Kentucky, Maryland, Massachusetts, New Jersey, New Mexico, North Carolina, Oklahoma, Oregon, Rhode Island, South Carolina, Utah, Virginia, and Wisconsin.

CO, carbon monoxide; NVDRS, National Violent Death Reporting System.

there were a sufficient number of deaths to explore trends, to have occurred contemporaneously with a small, non-significant, increase in CO suicides involving charcoal (IRR=1.02, 95% CI=0.97, 1.07) and an increase in helium suicides (IRR=1.20, 95% CI=1.15, 1.24). Thirty-eight of the 44 (86%) hydrogen sulfide suicides and 31 of the 36 (86%) nitrogen suicides occurred in the last 3 years of the study period (2010–2012).

The sensitivity of each source of information used in case identification (e.g., text fields) was often low (Table 1). For the coroner/medical examiner cause of death fields, for example, sensitivity ranged from 45% to 88% depending on the gas (e.g., 50% of all nitrous oxide cases were identified from this source), although the positive predictive value was generally high (with a range of 80%–100%; i.e., if a gas was identified in toxicology testing, the case was almost always a true case). For all cases, the vast majority of the time the gas of interest was identified through a text search of the narrative (Table 1). For example, for the 665 identified helium cases, in all but 36, the word “helium” appeared in either the medical examiner/coroner or law enforcement narrative text. However, potential cases in which the only information about the specific gas appeared in the narrative were also the largest source of false positives. For example, though propane was mentioned in 42 narratives, in only six instances was the death a propane case (i.e., caused by inhalation of propane).

Discussion

Approximately 4% of U.S. suicides are the result of gas inhalation, and the majority of these suicides (73%) are the result of CO poisoning. Consistent with studies that

have documented declines in CO suicides both in the U.S. and internationally,^{8–16} the frequency of suicide by CO, most often from motor vehicle or other engine exhaust, declined over the study period (from 336 in 2005 to 234 in 2012). By contrast, the subset of CO suicides that are the result of charcoal burning, though relatively uncommon in the U.S., remained relatively stable over the study period.

The most salient finding is that among suicides by gas, suicides by non-CO gases, especially helium, have become increasingly common. For example, during a period in which gas suicides overall remained stable, approximately 15% of gas suicides involved non-CO gas at the beginning of the study period, but by the end of the study period, more than 40% involved non-CO gas, principally helium.

Consistent with earlier smaller studies that noted the emergence of helium inhalation as a method of suicide in the U.S.,^{19–21} Australia and Sweden,²² Canada,²³ and the United Kingdom,¹ helium suicides increased substantially over the study period. In particular, the number of helium suicides jumped sharply in 2009, after which the number remained relatively stable. Suicide by other gases, including nitrogen and hydrogen sulfide, occur too infrequently to identify trends. However, the number of nitrogen and hydrogen sulfide suicides both increased in the latter part of the study period (2010–2012). Concern about suicide using hydrogen sulfide gas in the U.S. grew after a cluster of hydrogen sulfide suicides in Japan beginning in 2008,^{24,28} with hydrogen sulfide suicides being reported in the United Kingdom,^{1,29} and U.S.³⁰

With respect to the findings presented here, it is important to note that NVDRS is not yet a national system. However, despite the data being limited to the 16 states that had complete data for the years 2005–2012, these 16 states are broadly representative of the U.S. as a whole across a number of dimensions. For example, the 16 NVDRS states account for 26% of all U.S. suicides in 2005–2012 and 25% of the U.S. population (with corresponding suicide rates, respectively, of 12.2 and 12.0 per 100,000 person years). In addition, the proportion of suicides by routinely assessed methods is nearly identical in the 16 NVDRS states and the nation as a whole, as is racial composition (with whites constituting 78% of the population in the 16 NVDRS states and 80% of the population of the U.S. as a whole).

However, NVDRS has recently expanded to 32 states and there are plans to make it a fully national system. As such, NVDRS has the potential to provide a useful, comprehensive, and relatively easy to use source of information on suicide by gases. Small changes to NVDRS coding, through the addition of gas-specific variables, would greatly enhance its utility, and in so

doing, the capacity to identify and respond to emerging methods of suicide such as helium. Indeed, as the results reported here demonstrate, NVDRS can be used to identify gas suicide cases that otherwise would have gone undetected. This process is laborious and inefficient and requires active review of narrative information by researchers.

However, were the Centers for Disease Control and Prevention (CDC) to adopt the following recommendations, NVDRS could serve as an efficient surveillance system for gas suicides. Specifically, CDC should consider revising the NVDRS series of three variables, “weapons.” Instead of having only one option for “poisoning,” there should be an option for “poisoning by solid/liquid” and “poisoning by gas,” a change that would be consistent with ICD codes. Further, a new variable allowing the abstractor to indicate the specific type of gas used should be added and amended from time to time as new gases emerge. An existing variable —“source of gas”—exists in NVDRS but is used infrequently. Its use should be encouraged to allow, for example, for the easy differentiation of motor vehicle exhaust CO deaths from charcoal burning CO deaths. The authors found significant variation in whether suicide by a given gas was coded by the abstractor as “poison” or “suffocation” for weapon type. It is therefore recommended that abstractors classify gas suicides as poisoning, not suffocation, consistent with WHO ICD recommendations. Although beyond the scope of this paper, these recommendations could also be extended to deaths of undetermined intent to allow for better identification of poisonings among these deaths.

Historically, when access to commonly used, highly lethal suicide methods has decreased, the result has been a decrease not just in method-specific but overall suicide rates. For example, when the level of CO in domestic gas was greatly reduced in the United Kingdom in the mid-20th century, CO suicides declined dramatically, resulting in a substantial net decline in overall suicide rates.³¹ Similarly, both pesticide poisoning suicides and overall suicides fell in Sri Lanka after the availability of highly toxic pesticides was reduced.^{32–36} Conversely, increases in the adoption of suicide methods with relatively high case fatality rates, most commonly highly toxic gases such as CO from charcoal burning briquettes, have (in some instances) been accompanied by increases in overall suicide rates,^{4,18,37,38} highlighting the potential benefits of surveillance and early public health intervention measures.

The observed trends for gas suicides in the U.S., and for helium, nitrogen, and hydrogen sulfide in particular, may help focus subsequent analytic studies to search for relevant exposures that coincide with the observed jump in helium suicides. A number of studies have suggested

that the availability of “how to” information on suicide methods, either through published materials^{17,28,39,40} or on the Internet,^{7,29} may be associated with increases in the rate of suicide by these methods.

Conclusions

Small changes to NVDRS would allow for the ongoing identification of suicides by specific gases. Were these changes to be adopted, NVDRS would be well positioned to serve as a sentinel system for emerging trends in the uptake of gases such as helium, nitrogen, and hydrogen sulfide.

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